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GB 2206763 A GB 1273062 A EP 0354851 A2
US 5062689 A US 4957351 A US 3858001 A

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(54) **Stereoscopic display using a light modulator**

(57) An auto stereoscopic 3D display comprises a hybrid sandwich (11) comprising a first lenticular screen (12), a spatial light modulator (13), a diffuser (14), and second lenticular screen (16). A plurality of light sources 1 to 4 produce in turn divergent light beams which are modulated by the modulator (13) with two interlaced views. The hybrid sandwich (11) projects the views in different directions towards an observer (17). The different 2D views are thus visible from directions corresponding to the directions in which the views were captured during recording of a 3D image. Each eye of the observer (17) sees a single view across the whole of the display. The display may include a 2-D light source array. A lenticular array may comprise of cylindrical or spherical, converging lenses. A lenticular array may be replaced by an opaque screen with an array of apertures.

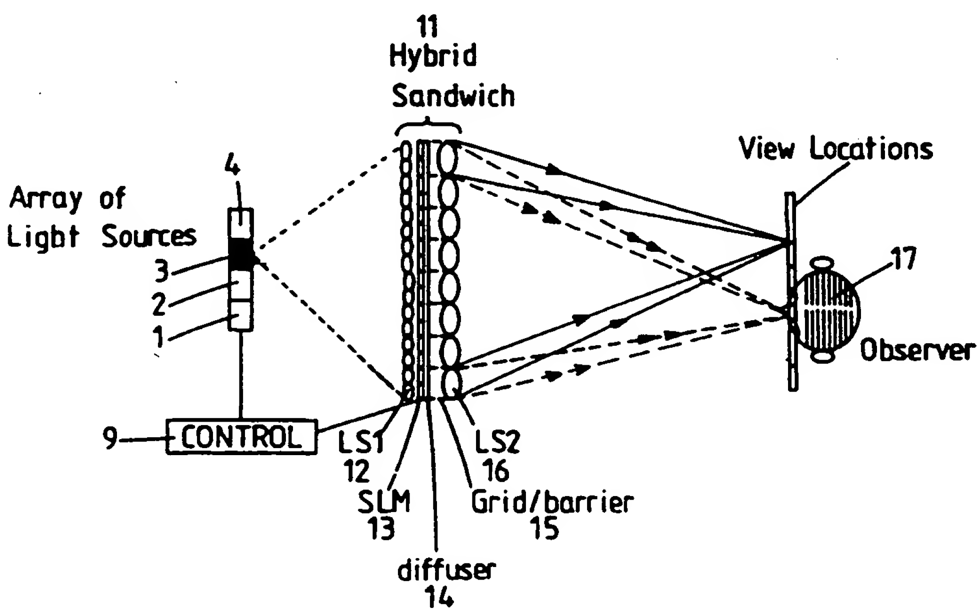


FIG.3.

GB 2 272 555 A

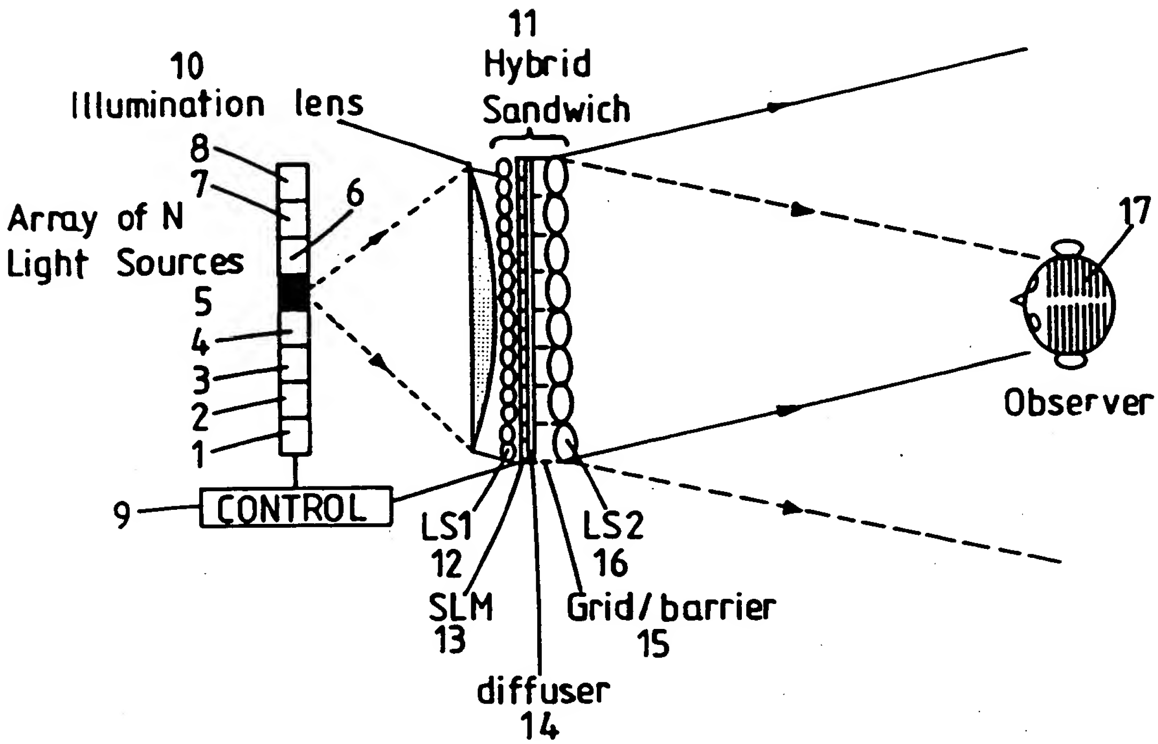

10
Illumination lens
11
Hybrid
Sandwich
8
7
6
Array of N
Light Sources
5
4
3
2
1
17
Observer
9
CONTROL
LS1
12
SLM
13
LS2
16
Grid/barrier
15
diffuser
14

FIG.1.

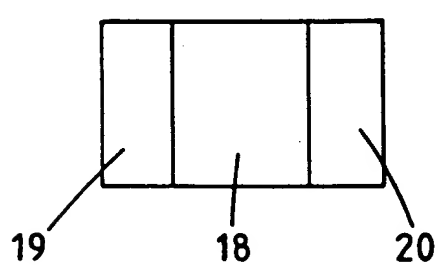

19
18
20

FIG.2.

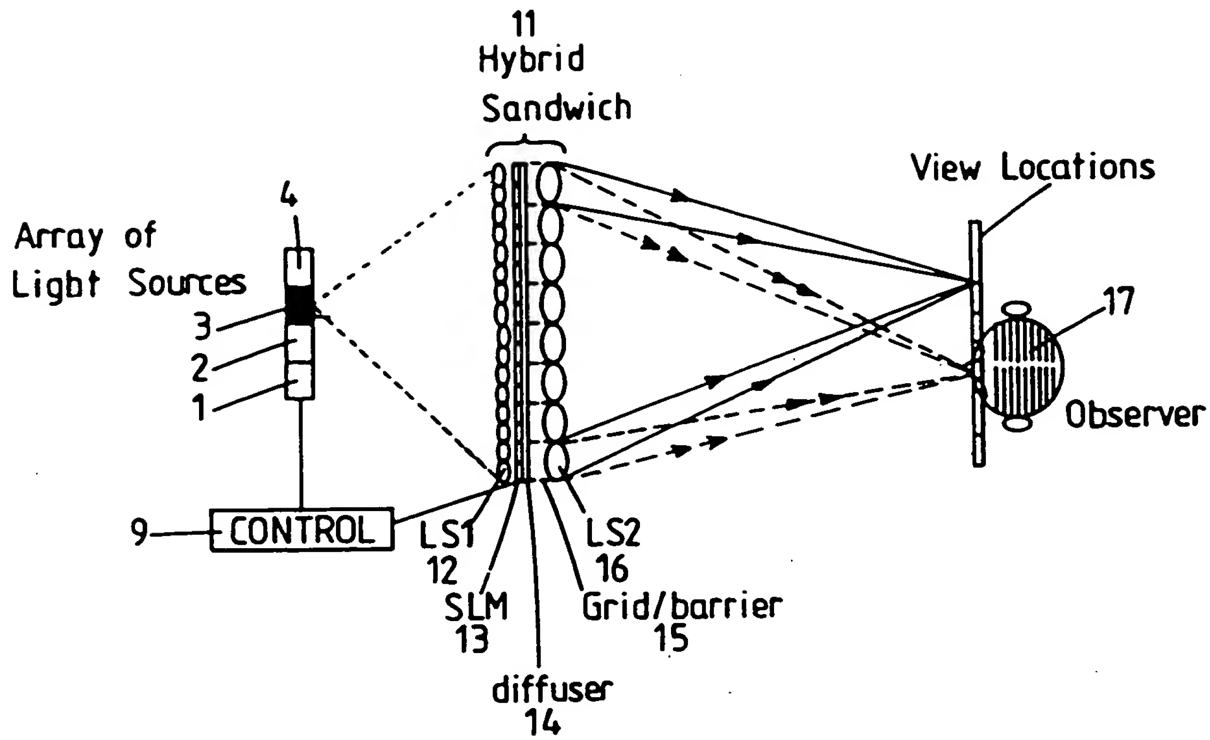

11
Hybrid
Sandwich
View Locations
4
Array of
Light Sources
3
2
1
17
Observer
9
CONTROL
LS1
12
SLM
13
diffuser
14
LS2
16
Grid/barrier
15

FIG.3.

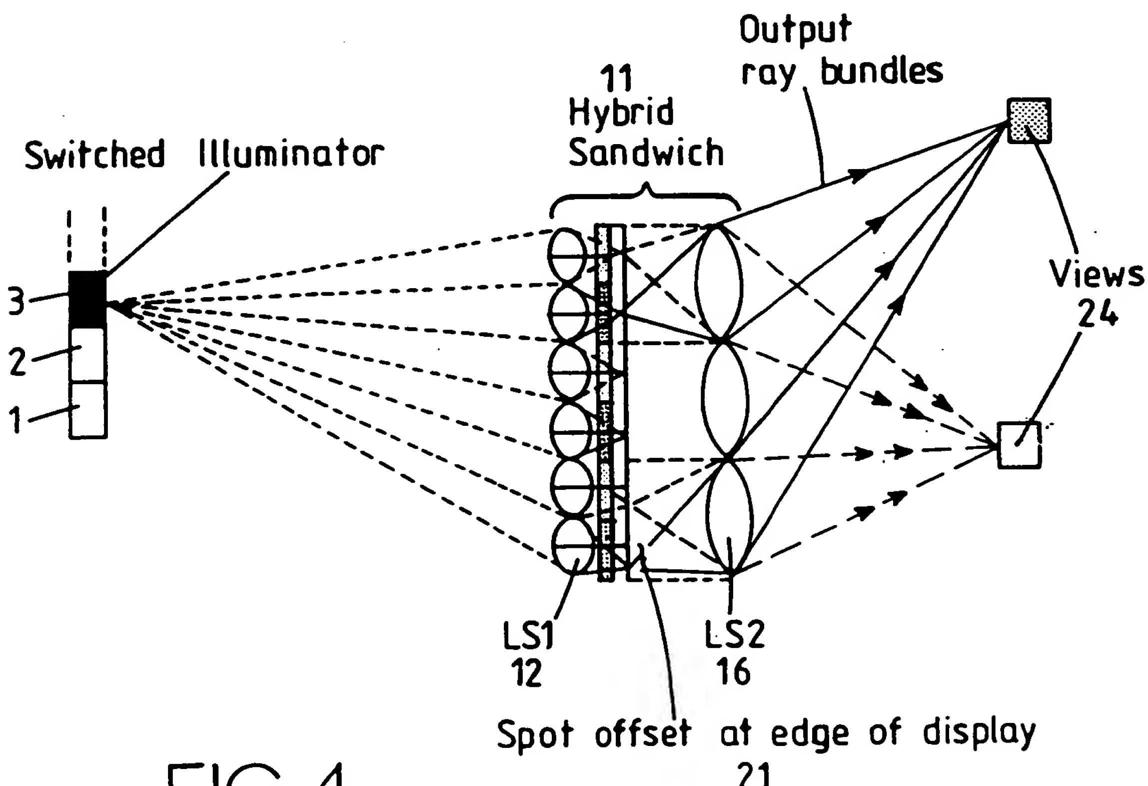

Output
ray bundles
11
Hybrid
Sandwich
Switched Illuminator
3
2
1
Views
24
LS1
12
LS2
16
Spot offset at edge of display
21

FIG.4.

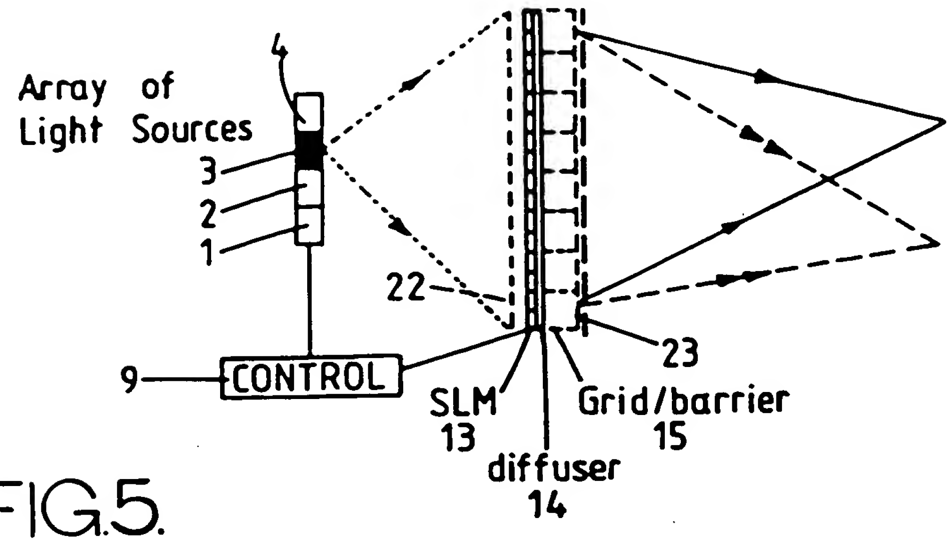


FIG.5.

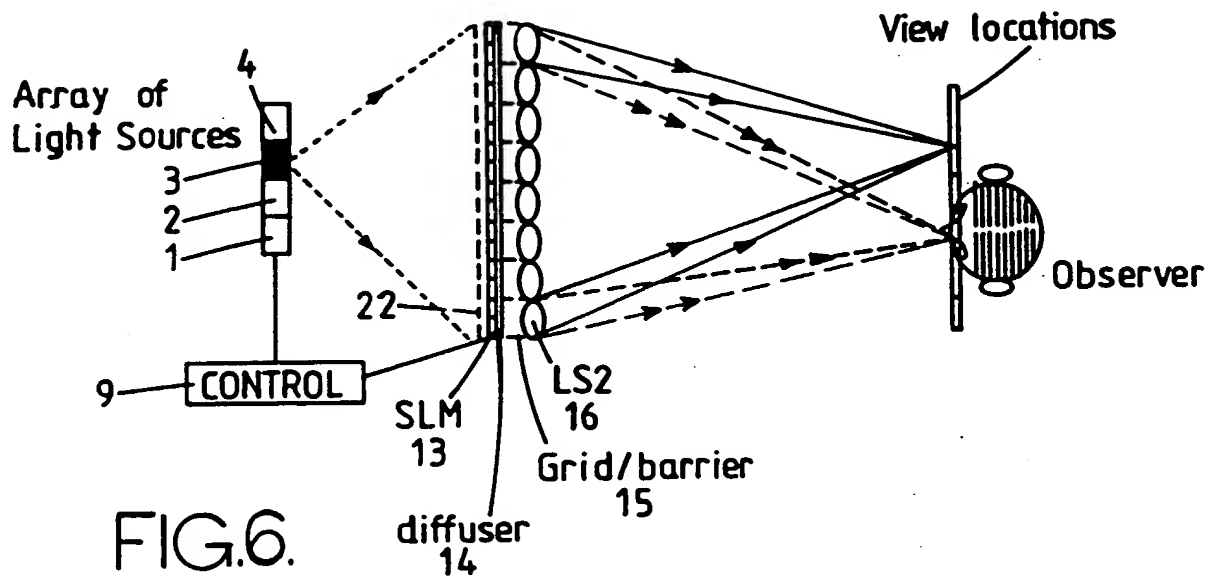


FIG.6.

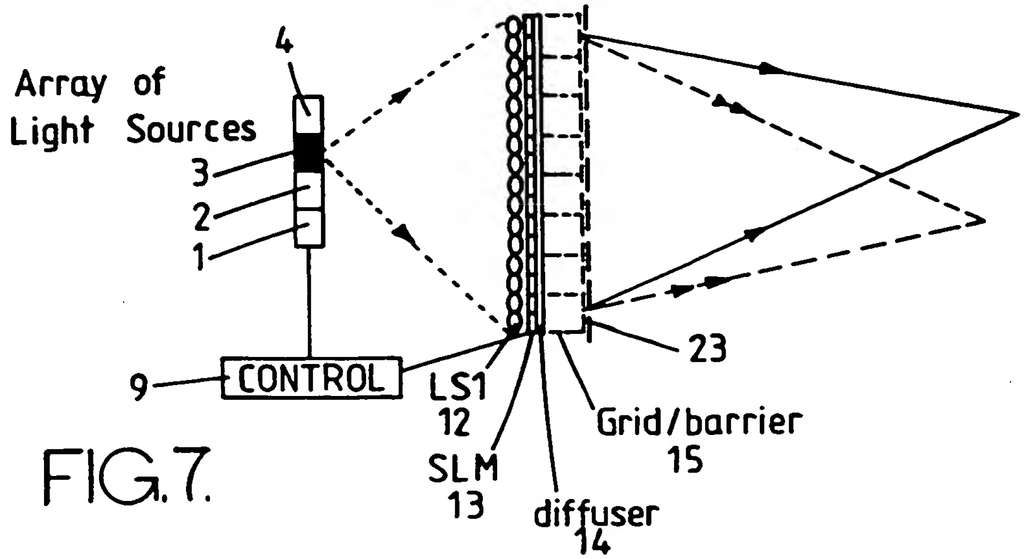
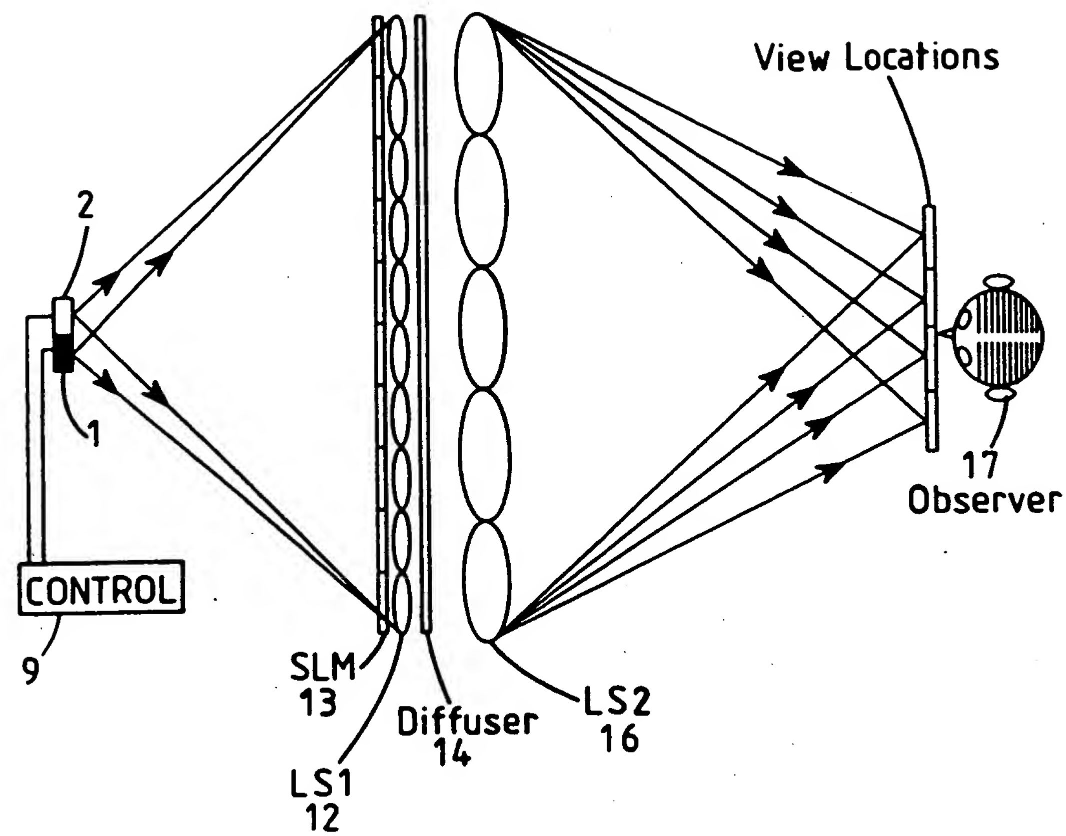


FIG.7.

FIG.8.


View Locations
2
1
17
Observer
CONTROL
9
SLM
13
LS1
12
Diffuser
14
LS2
16

DISPLAY

The present invention relates to a display. Such a display may be used as a non-holographic three-dimensional (3D) display which is capable of forming a 3D image of opaque moving objects.

A known type of 3D display creates an illusion of a 3D image to a human observer by displaying a plurality of two-dimensional (2D) images in sequence. Each of the 2D images comprises a view of an object from a particular direction and is replayed in that direction. The perceived quality of 3D images provided by such techniques improves as the size of the display is increased.

British Patent Application No.9210399.3 discloses a 3D display in which temporal and spatial multiplexing are used to provide an autostereoscopic 3D image. By combining temporal and spatial multiplexing, an increased number of 2D views can be provided. However, the number of 2D views is limited by the maximum update rate and resolution of presently available spatial light modulators (SLM).

When a display of this type is increased in size so as to provide a relatively large display, each eye of an observer located at a given position will not see the same 2D view across the whole of the screen. Instead, the eye will see juxtaposed vertical slices of two or more different views on the screen with each slice having a width which is dependent on the position of the observer with respect to the display and on the display optical geometry. Each eye sees a different set of view slices which would give the appearance of a 3D image. However, the view slices can cause problems in the perception of a 3D image.

If a limited number of 2D views is available because of limited SLM update rate and resolution, then there may be an insufficient number of view slices to fill the display while maintaining the correct imaging directions for each view, so that the observer sees a 3D image over only part of the display. Thus, the display size is limited by the maximum update rates and resolutions of presently available SLMs.

According to a first aspect of the invention, there is provided a display comprising: at least one light source for producing a divergent beam of light; a first array of lenses arranged to receive the divergent light beam from the or each light source; a spatial light modulator comprising a plurality of light-modulating cells, each of which is arranged to modulate light to or from a respective lens of the first array; and a second array of lenses, each of which is arranged to receive light modulated by at least one of the cells of the modulator.

Preferably the first array of lenses is located between the at least one light source and the spatial light modulator. Alternatively, the spatial light modulator may be located between the at least one light source and the first array of lenses.

The lenses of the first and second arrays are preferably converging lenses. For instance, the first and second arrays may comprise lenticular screens, for instance in the form of a plurality of parallel elongate lenticules having cylindrical convergent properties. The at least one light source may comprise a linear array of light sources extending perpendicularly to the lenticules. Such an arrangement may be used to provide horizontal parallax. Where both horizontal and vertical parallax is required, the first and second arrays may comprise 2D arrays of lenses, for instance in the form of microlens

arrays. The lenses may be of the spherical convergent type and the at least one light source may comprise a two dimensional array of light sources. In either case, the light sources may be illuminated one at a time sequentially by suitable control means. The or each light source may be contiguous with the or each adjacent light source.

The pitch of the lenses of the first array may be substantially equal to the pitch of the cells of the spatial light modulator. This pitch may be less than the pitch of the lenses of the second array, which may for instance be an integer multiple of the pitch of the lenses of the first array and the pitch of the cells of the modulator.

A diffuser may be located between the modulator and the second array. The diffuser is preferably located at or adjacent a common focal plane of the lenses of the second array, and at an image plane of the or each light source imaged by the first array.

An opaque barrier may be disposed between the modulator or diffuser and the second array for blocking transverse light paths.

According to further aspects of the invention, the first array of lenses and/or the second array of lenses may be replaced by a respective parallax barrier.

It is thus possible to provide a display which is capable of being used as a large 3D display with each eye of an observer at a given position observing a single 2D view across the whole of the display. The eyes of the observer see different 2D views, thus giving the appearance of a 3D image. Such a display has many possible uses, for instance in television, computer aided

design, medical imaging, video games, simultaneous 3D and 2D presentation, and virtual reality displays.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic plan view of a display of the type disclosed in British Patent Application No.9210399.3;

Figure 2 illustrates the appearance of a large display of the type shown in Figure 1 when seen with one eye of an observer;

Figure 3 is a diagrammatic plan view of a 3D display constituting a first embodiment of the invention;

Figure 4 illustrates diagrammatically part of the display of Figure 3 in more detail; and

Figures 5, 6, 7, and 8 are diagrammatic plan views of 3D displays constituting second, third, fourth, and fifth embodiments, respectively, of the invention.

Like reference numerals refer to like parts throughout the drawings.

The display shown in Figure 1 comprises a linear array of N light sources 1 to 8, where N=8 in the arrangement shown. The light sources 1 to 8 are contiguous so as to form a continuous strip. The light sources are connected to a control circuit 9, which causes the light sources to be illuminated one at a time repetitively in order, Figure 1 indicating that the light source 5 is illuminated. The linear array of light sources 1 to 8 is disposed in the focal plane of an illumination or

collimating system 10, which is shown as a plano-convex lens having a cylindrical convex surface. The system 10 produces collimated light from each point of each of the light sources 1 to 8. Because the light sources have finite dimensions, the light output of the collimating system has a spread of angles.

Collimated light from the lens 10 is directed towards a hybrid sandwich 11 at an angle which is determined by which of the light sources 1 to 8 is presently illuminated. The hybrid sandwich comprises a lenticular screen (LS1) 12 formed by a plurality of contiguous cylindrical converging lens elements or lenticules having a horizontal pitch p. The screen 12 is followed by a SLM 13 in the form of a 2D liquid crystal device which is connected to the control circuit 9. The SLM 13 comprises a 2D array of picture elements whose light transmission properties (and colour transmission properties for a colour display) are controlled by the control circuit 9.

The SLM is followed by a diffuser 14 which is separated by a grid or barrier 15 for blocking lateral light paths from a further lenticular screen (LS2) 16. The screen 16 is similar to the screen 12 but has a horizontal pitch equal to Mp, where M is an integer greater than 1.

In use, the light rays from the illuminated light source 5 are collimated into parallel light rays by the system 10 and are focused by the screen 12 through the SLM 13 onto the diffuser 14. The picture elements of the SLM 13 are controlled by the control circuit so as to provide, for instance, two views of the image taken from different directions during image capture. The two views are interlaced such that alternate strip portions correspond to a respective one of the views.

The picture elements of the SLM 13 control the amount

(and colour for a colour display) of light passing through the SLM so that a 2D array of images of the light source 5 is formed on the diffuser 13 corresponding to the two interlaced views. Each of the lenticules of the screen 16 converts the images on the diffuser 14 into output ray bundles whose angles of emission from the hybrid sandwich 11 depend on the lateral locations of the images on the diffuser 14 with respect to the optical axes of the lenticules. The two views represented on the SLM 13 are therefore visible from different angles corresponding to the angles of the object from which the views were taken during image capture. The grid or barrier 15 prevents each lenticule of the screen 16 from imaging the light images formed on the diffuser 14 and associated with adjacent lenticules of the screen 16.

After the light source 5 has been actuated for a predetermined time, the control circuit 9 deactivates the light source 5 and causes the SLM 13 to display the next pair of interlaced views. The next light source 4 is then activated and the screen 12 images the light through the SLM 13 onto regions of the diffuser 14 which are laterally displaced with respect to the images formed when the light source 5 is illuminated. Thus, the lenticular screen 16 provides output ray bundles directed at different angles corresponding to the directions of the view of the object during image capture.

This sequence of operation continues until each of the light sources of the linear array has been illuminated in turn, with the views represented on the SLM corresponding to a single "frame" of the 3D image. The whole sequence is then repeated for new sets of views representing consecutive frames constituting consecutive 3D images, the rate of repetition being sufficiently large to provide a substantially flicker-free image. The number of views making up each 3D image is equal to MxN.

Although Figure 1 shows a display capable of providing 16 views per image, practical SLMs may have refresh rates limited to 100 Hz so that, in order to provide a flicker-free image, the array of light sources may comprise only two sources. Similarly, practical SLMs may have resolution limits such that only two views at a time can be produced. Thus, the number of views per frame may be limited to four.

It is intended that, for each given position of the observer within a region in front of the display for which a 3D effect is to be produced, each eye of the observer sees only one of the views across the whole display in the direction corresponding to that from which the 2D view was captured. However, for relatively large 3D displays, the limited resolution and frame rate of the SLM 13 and the optical geometry of the display can result in the appearance illustrated in Figure 2. Thus, in a middle region 18 of the display, one eye of the observer sees part of a first view. However, at edge regions 19 and 20 of the display, the same eye of the observer sees parts of second and third different views. The view slices can cause problems in the perception of a 3D image.

The display shown in Figure 3 differs from that shown in Figure 1 in that the collimating system 10 is omitted. Also, the array of light sources is shown as comprising only four such sources 1 to 4. Otherwise, the control circuit 9 and the hybrid sandwich 11 are substantially identical to the corresponding parts of the display of Figure 1.

In use, the control circuit 9 controls the light sources 1 to 4 and the SLM 13 as described with reference to Figure 1. However, the hybrid sandwich 11 receives a divergent beam of light from each of the light sources 1

to 4, so that the light sources are imaged by the lenticules of the screen 12 through the SLM 13 onto different positions on the diffuser 14. When each light source is illuminated, its image on the diffuser 14 is at the same position as in the display of Figure 1 for the lenticule of the screen 12 on whose optical axis the light source is located. For other lenticules, the light source image is laterally displaced progressively further towards the edge of the diffuser as the lateral distance of the lenticule from the above-mentioned optical axis increases. This offset is illustrated at 21 in Figure 4 with the light source 3 illuminated. Thus, the direction of light emerging from each lenticule of the screen 16 varies progressively across the display, so that each view of the interlaced pair of views is projected towards a single point instead of in a single direction as for the display of Figure 1. Thus, an observer 17 will see a single but different 2D view with each eye over the whole of the display so that the appearance of a full screen 3D image will be produced. Figure 4 illustrates at 24 the points or regions towards which the two views produced when the light source 3 is illuminated are projected.

Such an arrangement provides a limited region from which an observer may perceive the 3D effect. For instance, for a display of size 0.5 meter with an observer located 1 meter from the front surface, a display providing four views permits the observer to maintain a 3D image within a region which extends approximately 200 mm. laterally on either side of a normal to the centre of the display and 260 mm. in front of and behind the observer position. An SLM frame rate of 100 Hz permits a non-flickering image to be perceived.

Figure 5 illustrates a display which differs from that of Figure 3 in that the lenticular screens 12 and 16 are replaced by parallax barriers 22 and 23, respectively.

Each of the barriers comprises a plurality of slits arranged perpendicularly to the axis of the array of light sources 1 to 4. The pitch of the slits of the barrier 22 is equal to the pitch of the elements of the SLM 13, whereas the pitch of the slits of the barrier 23 is equal to twice that of the barrier 22. Operation of this display is the same as that of the display shown in Figure 3.

Figure 6 shows a display which differs from that of Figure 3 in that the lenticular screen 12 is replaced by a parallax barrier 22 of the type shown in Figure 5. The display of Figure 7 differs from that shown in Figure 3 in that the lenticular screen 16 is replaced by a parallax barrier 23 of the type shown in Figure 5. The operations of the displays of Figures 6 ad 7 are the same as that of the display shown in Figure 3.

Figure 8 shows a display which differs from that of Figure 3 in that the lenticular screen 12 follows the SLM 13 and in that the grid or barrier 15 has been omitted (although it may be included). The SLM 13 thus modulates the divergent light beams from the light sources 1, 2 (only two are shown in Figure 8) and the modulated beams are imaged onto the diffuser 14 by the lenticular screen 12.

The lenticular screen 12 and or the lenticular screen 16 may be replaced by a respective parallax barrier of the type shown in Figures 5 to 7. Although the lenticular screen 12 (or the parallax barrier) may be located behind the SLM 13 as shown in Figure 8, it is at present preferred to place it in front of the SLM 13 as shown in Figures 3 to 7.

It is thus possible to provide a relatively large 3D display in which, from any point within a region from

which the 3D effect may be viewed, each eye of an observer sees a single view extending across the whole of the display. This is achieved without the need to increase the frame rate or resolution of the SLM.

CLAIMS

1. A display comprising: at least one light source for producing a divergent beam of light; a first array of lenses arranged to receive the divergent light beam from the or each light source; a spatial light modulator comprising a plurality of light-modulating cells, each of which is arranged to modulate light to or from a respective lens of the first array; and a second array of lenses, each of which is arranged to receive light modulated by at least one of the cells of the modulator.

2. A display as claimed in Claim 1, in which the first array of lenses is located between the at least one light source and the spatial light modulator.

3. A display as claimed in Claim 1, in which the spatial light modulator is located between the at least one light source and the first array of lenses.

4. A display as claimed in any one of the preceding claims, in which the lenses of the first array are converging lenses.

5. A display as claimed in any one of the preceding claims, in which the lenses of the second array are converging lenses.

6. A display as claimed in Claim 5 when dependent on Claim 4, in which the first and second arrays comprise first and second lenticular screens, respectively.

7. A display as claimed in Claim 6, in which each of the first and second lenticular screens comprises a plurality of parallel elongate lenticules having cylindrical convergent properties.

8. A display as claimed in Claim 7, in which the at least one light source comprises a linear array of light sources extending perpendicularly to the lenticules.

9. A display as claimed in Claim 5 when dependent on Claim 4, in which the first and second arrays comprise first and second two dimensional arrays of lenses, respectively.

10. A display as claimed in Claim 9, in which the lenses of the first and second arrays have spherical convergent properties.

11. A display as claimed in Claim 9 or 10, in which the at least one light source comprises a two dimensional array of light sources.

12. A display as claimed in any one of the preceding claims, in which the pitch of the lenses of the first array is substantially equal to the pitch of the cells of the spatial light modulator.

13. A display as claimed in Claim 12, in which the pitch of the lenses of the second array is greater than the pitch of the lenses of the first array.

14. A display as claimed in Claim 13, in which the pitch of the lenses of the second array is substantially equal to the product of the pitch of the lenses of the first array and an integer greater than 1.

15. A display as claimed in any one of the preceding claims, in which a diffuser is disposed between the spatial light modulator and the second array.

16. A display as claimed in Claim 15, in which the diffuser is disposed at or adjacent a common focal plane

of the lenses of the second array and that an image plane of the or each light source imaged by the first array.

17. A display as claimed in any one of the preceding claims, in which an opaque barrier is disposed between the spatial light modulator and the second array for blocking transverse light paths.

18. A display comprising: at least one light source for producing a divergent beam of light; a first opaque screen having formed therein a first array of apertures for receiving the divergent beam from the or each light source; a spatial light modulator comprising a plurality of light-modulating cells, each of which is arranged to modulate light to or from a respective aperture of the first array; and a second opaque screen having formed therein a second array of apertures, each of which is arranged to receive light modulated by at least one of the cells of the modulator.

19. A display comprising: at least one light source for producing a divergent beam of light; an array of lenses arranged to receive the divergent light beam from the or each light source; a spatial light modulator comprising a plurality of light-modulating cells, each of which is arranged to modulate light to or from a respective lens of the array; and an opaque screen having formed therein an array of apertures, each of which is arranged to receive light modulated by at least one of the cells of the modulator.

20. A display comprising: at least one light source for producing a divergent beam of light; an opaque screen having formed therein an array of apertures for receiving the divergent beam from the or each light source; a spatial light modulator comprising a plurality of light-modulating cells, each of which is arranged to modulate

light to or from a respective aperture of the array; and an array of lenses, each of which is arranged to receive light modulated by at least one of the cells of the modulator.

21. A display as claimed in any one of the preceding claims, in which the spatial light modulator comprises a liquid crystal device.

22. A display as claimed in any one of the preceding claims, in which the at least one light source comprises a plurality of light sources.

23. A display as claimed in Claim 22, in which each of the light sources is contiguous with the or each adjacent light source.

24. A display as claimed in Claim 22 or 23, further comprising control means for sequentially illuminating the light sources.

25. A display as claimed in Claim 24, in which the control means is arranged to control the spatial light modulator in accordance with a plurality of sequentially presented images representing a frame of a three dimensional image, each image comprising at least one view.

26. A display substantially as hereinbefore described with reference to and as illustrated in Figures 3 and 4 or Figure 5 or Figure 6 or Figure 7 or Figure 8 of the accompanying drawings.

Patents Act 1977 15

xaminer's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9223652.0

Relevant Technical fields (i) UK Cl (Edition L) G5C (CHA,CHC) H4F (FDD) (ii) Int Cl (Edition 5) H04N, G09F	Search Examiner J A WATT
Databases (see over) (i) UK Patent Office (ii) ONLINE DATABASE: WPI	Date of Search 1 FEBRUARY 1993

Documents considered relevant following a search in respect of claims

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2206763 A (ARL TRAVIS) see lines 18-21 page 5 and 21-29 page 8)	1 at least
A	EP 0354851 A2 (NTT) whole document	1 at least
A	US 4957351 A (SHARP) whole document	1 at least
X	US 3858001 A (HONEYWELL) see Figures 1 and 2 and lines 43-44 column 6. (Note lenticular layers 52 and 60 and modulation layer 58.)	1 at least